SCIENTIFIC JOURNAL OF SPORT AND PERFORMANCE

ORIGINAL ARTICLE

The influence of immersive virtual reality and an auditory stimulus on perceived exertion and cardiovascular responses during submaximal treadmill exercise

Jake Pirnazar . *Airway and UC Fit Digital Health-Exercise Physiology Research Laboratory. David Geffen School of Medicine. University of California Los Angeles. Los Angeles, CA, United States of America.*

Trent Yamamoto. *Airway and UC Fit Digital Health-Exercise Physiology Research Laboratory. David Geffen School of Medicine. University of California Los Angeles. Los Angeles, CA, United States of America.*
Chobanian and Avedisian School of Medicine. Boston University. Boston, MA, United States of America.

Trinabh K. Sahni. *Airway and UC Fit Digital Health-Exercise Physiology Research Laboratory. David Geffen School of Medicine. University of California Los Angeles. Los Angeles, CA, United States of America.*

Nicholas Thomson. *Airway and UC Fit Digital Health-Exercise Physiology Research Laboratory. David Geffen School of Medicine. University of California Los Angeles. Los Angeles, CA, United States of America.*

Joshua A. Kidwell. *Airway and UC Fit Digital Health-Exercise Physiology Research Laboratory. David Geffen School of Medicine. University of California Los Angeles. Los Angeles, CA, United States of America.*
School of Medicine. Creighton University. Omaha, NE, United States of America.

Brett A. Dolezal. *Airway and UC Fit Digital Health-Exercise Physiology Research Laboratory. David Geffen School of Medicine. University of California Los Angeles. Los Angeles, CA, United States of America.*

ABSTRACT

Immersive virtual reality (IVR) can affect how physical exercise is perceived. However, previous investigations with IVR modalities have focused primarily on visual, rather than auditory, aspects of the IVR environment. Accordingly, it remains unclear whether adding a congruent environmental auditory stimulus to visual IVR provides perceptual or cardiovascular benefits beyond visual immersion alone during standardized exercise. This study evaluated the effects of an adjunct audio component combined with IVR during exergaming-based cardiovascular training. Utilizing a randomized crossover design, 18 participants each performed three exercise trials: traditional treadmill workout (control), treadmill workout using IVR immersion with the Octonic application without audio (IVR-WOA), and treadmill workout using IVR with an auditory stimulus (IVR-WA). Assessments of heart rate and ratings of perceived exertion (RPE), measured in 5-minute increments, were completed. Outcomes were analyzed using repeated-measures ANOVA, with effect sizes and 95% confidence intervals used to characterize the magnitude and precision of observed differences. RPE increased over time in all conditions, with the IVR-WA condition producing a significantly lower RPE at 20 minutes compared with both control (p = .001) and IVR-WOA (p < .001). Notably, no differences in RPE between IVR-WOA and control were detected. Average heart rate was significantly lower during IVR-WA compared with control (p = .002), and peak heart rate was reduced in both IVR conditions relative to control. However, both average and peak heart rate did not differ between IVR-WOA and IVR-WA. These findings suggest that an auditory stimulus may play a key role in attenuating perceived exertion, which visual immersion alone did not produce, and that the cardiovascular and perceptual consequences of immersive sensory augmentation may have different sensory requirements. These findings advance current knowledge by demonstrating that environmental auditory stimulation may provide a perceptual benefit beyond visual IVR alone, while not producing an additional cardiovascular benefit, suggesting that the sensory components of immersive exercise environments may differentially influence subjective and physiological responses.

Keywords: sport medicine; exergaming; cardiovascular health; virtual reality; immersive virtual reality.

Cite this article as:
Pirnazar, J., Yamamoto, T., Sahni, T. K., Thomson, N., Kidwell, J. A., & Dolezal, B. A. (2027). The influence of immersive virtual reality and an auditory stimulus on perceived exertion and cardiovascular responses during submaximal treadmill exercise. *Scientific Journal of Sport and Performance*, *6*(1), 177-190. https://doi.org/10.55860/EHFX2047

Corresponding author. *Airway and UC Fit Digital Health-Exercise Physiology Research Laboratory. David Geffen School of Medicine. University of California Los Angeles. Los Angeles, CA, United States of America.*
E-mail: jakep007@g.ucla.edu
Submitted for publication July 08, 2026.
Accepted for publication September 25, 2026.
Published November 25, 2026.
Scientific Journal of Sport and Performance. ISSN 2794-0586.
©Asociación Española de Análisis del Rendimiento Deportivo. Alicante. Spain.
doi: https://doi.org/10.55860/EHFX2047

INTRODUCTION

Regular physical activity is one of the most established determinants of health, with consistent evidence linking aerobic exercise to reduced risk of cardiovascular disease, type 2 diabetes, certain cancers, depression, and all-cause mortality (Piercy et al., 2018). Despite these benefits, approximately 80% of US adults are insufficiently active and do not meet the recommended 150 minutes of moderate-intensity aerobic activity per week (Piercy et al., 2018). Poor adherence represents one of the most significant barriers preventing adults from achieving their fitness goals. Among adults who begin exercise programs, approximately half will discontinue their program within the first 6 months (Robison & Rogers, 1994).

Poor adherence can be attributed to a variety of factors, such as unstimulating interventions, psychological and physical discomfort, or time constraints. Discomfort is of particular interest because it is not merely an unpleasant feature of a given exercise bout, but a plausible determinant of whether that bout is repeated. Affective response during a single acute bout of moderate-intensity exercise prospectively predicts self-reported physical activity participation at both 6 and 12 months in previously sedentary adults (Williams et al., 2008), and the affective experience of exercise may factor into exercise prescriptions (Ekkekakis et al., 2011).

Nascent technology and interventions designed to reduce the subjective burden of exercise have been created. Among these innovations, sensory based attentional manipulations may offer considerable benefits. Using external stimuli to direct attention away from the uncomfortable sensations of exercise and instead towards an engaging external environment, these new modalities aim to address the previous barriers associated with monotonous exercise. The theoretical basis for this approach is that attentional resources during exercise are limited, such that external stimuli compete with interoceptive signals for access to conscious awareness (Hutchinson & Tenenbaum, 2007). Earlier work in this area has examined music, video, and combined audiovisual interventions, with mixed findings on autonomic outcomes but generally consistent reductions in perceived exertion at matched workloads (Hutchinson et al., 2015; Yamashita et al., 2006). More recently, immersive virtual reality (IVR) has been investigated as a means of making exercise more pleasant. A systematic review of twenty studies comprising 798 participants concluded that IVR-delivered physical activity was associated with greater enjoyment, reduced perceived exertion, and higher self-efficacy, intrinsic motivation, and exercise intention relative to both traditional and non-immersive comparators (Mocco et al., 2024). Immersive, dissociative nature-based environments can enhance enjoyment and distraction from bodily sensations during exercise relative to a non-immersive control, with immersion in the stimulus rather than the sense of presence appearing to drive these effects (Jones & Wheat, 2023). Previous investigation in our laboratory has found that IVR can attenuate mean heart rate and ratings of perceived exertion while walking on a treadmill (Yamamoto et al., 2024).

However, given that IVR is a multisensory intervention, the discrete contributions of its individual sensory channels during exercise have yet to be determined. Outside the exercise context, this decomposition was performed by Naef et al. (2022), who examined the effects of audiovisual, auditory-only, and visual-only nature stimuli against no artificial sensory input in supine participants. The authors found that heart rate was lowest during the audiovisual and visual-only conditions, whereas the steadiest reduction in respiration rate, the lowest blood pressure, and the greatest reported reduction in awareness of the real-world environment occurred only when both channels were delivered together. Within the exercise literature, by contrast, the two channels have been varied in tandem. Jones and Ekkekakis (2019) contrasted a condition combining a head-mounted display with headphones against a screen-and-speaker comparator, and Barbour et al. (2024) held visual and auditory content constant across immersive and two-dimensional presentations, noting

 © 2027 ARD Asociación Española

explicitly that their design could not determine which elements of the immersive experience produced the observed benefits. Where auditory content has been manipulated during exercise, it has almost invariably been music, which acts through attentional dissociation but additionally through rhythmic entrainment, movement synchronisation, arousal regulation, and motivational and affective qualities that operate independently of any accompanying visual environment (Karageorghis & Priest, 2012). Non-musical environmental sound matched to a virtual scene carries no rhythmic or motivational content, is meaningful only in relation to the environment it accompanies, and may therefore act on the exercise experience through a different route.

While prior work has demonstrated that IVR during exercise can produce favorable changes in affective response, perceived exertion, and exercise enjoyment, several knowledge gaps remain. First, the relative contributions of visual versus combined audiovisual immersion have not been systematically examined within the same exercise protocol, leaving open both whether the addition of auditory content extends the benefits of visual immersion alone and whether it does so equally across cardiovascular and perceptual outcomes. Second, autonomic outcomes during IVR exercise have been inconsistently reported (Rutkowski et al., 2021), with most studies measuring either heart rate or affect but few examining how autonomic and perceptual outcomes co-vary or dissociate. Third, fixed-workload designs that allow direct comparison of physiological responses at matched metabolic demand are relatively uncommon in this literature, limiting causal inference about how attentional manipulations affect the exercise response itself rather than self-selected exercise behavior.

Therefore, the present study aimed to determine how an auditory component combined with IVR affects cardiovascular and perceptual responses during treadmill walking. Participants completed three conditions at an identical treadmill speed and grade: a control condition without sensory augmentation, an IVR-only condition, and a condition combining the same IVR environment with a non-musical playlist of environmental sounds selected to match the virtual scene. Holding both the visual environment and the external workload constant while manipulating only the auditory channel isolates the contribution of a single sensory modality within an otherwise identical immersive experience. To our knowledge this manipulation has not previously been performed during exercise at fixed external workload. We hypothesized that both immersive conditions would reduce heart rate and perceived exertion relative to control, and that the combined audiovisual condition would produce the largest reductions in both outcomes.

METHODS

Participants

An unpublished exploratory pilot study was conducted independently at UCLA in eight collegiate-aged males using a similar design. All pilot participants provided written informed consent, and the pilot protocol was approved by the UCLA Institutional Review Board (IRB No. 11-003190). Data from the pilot study were used solely to estimate the effect size for the a priori power analysis; assuming $\alpha = .05$ and statistical power of 80% ($\beta = .20$), the required sample size for the present study was $N = 18$. The present investigation was conducted separately at an independent fitness facility in Los Angeles, California. Participants enrolled in the current study provided written informed consent under a single Institutional Review Board approval (sIRB: BRANY, NY, USA). All procedures in both studies were conducted in accordance with the ethical principles of the Declaration of Helsinki.

Participants with a significant history of cardiovascular, metabolic, and/or musculoskeletal conditions that may have affected their ability to perform physical exercise or confer a substantial risk of injury were excluded.

To standardize the participant pool and their potential adaptations to the interventions, only participants who did not have any prior experience with virtual reality systems were recruited for this study.

Study design

In this randomized crossover design, participants performed three different trials, each of which involved walking for 20 minutes at 3.5 mph at a 0° incline. One trial was completed without IVR, one was completed with IVR, and one was completed with IVR and an auditory stimulus. An investigator, different from the one conducting the trial, generated the trial order for each participant using an online random sequence generator. Each participant was then randomly assigned a number corresponding to their randomized sequence. During all trials, any interfering noise (e.g., conversations and mobile device notifications) was silenced to ensure effective immersion into the virtual environment. For the condition with audio, an investigator compiled a VR-enhancing playlist (VREP) of noises intended to enhance immersion into the environment, including birds chirping and wind blowing. The playlist played throughout each 20-minute session, with noises presented in a randomized order. The VREP consisted exclusively of non-musical environmental sounds selected to correspond with the virtual canyon environment. It contained no music, rhythmic beat, lyrics, or motivational content and was intended to augment environmental immersion rather than provide a music-based exercise stimulus. For baseline measures, body mass was measured on a calibrated medical scale (accuracy ±0.1 kg), and height was determined using a precision stadiometer (Seca, Hanover, MD, USA; accuracy ±0.01 m). Body fat percentage was measured using a validated octipolar, multi-frequency, multi-segmental bioelectrical impedance analyzer (InBody Co., Seoul, Republic of Korea).

IVR Intervention

The IVR intervention made use of an innovative software application (Octonic VR, New York, NY, USA) developed to enable a variety of viewing experiences while walking on a treadmill. Participants using the Head Mounted Display (HMD) (Meta Quest 3, Menlo Park, CA, USA) entered a standardized environment simulating a canyon (i.e. "*Caves and Canyons*") shown in Figure 1. The same headset, Octonic software configuration, and 'Caves and Canyons' virtual environment were used for both IVR conditions, such that the presence or absence of the auditory stimulus represented the principal experimental difference between the two immersive conditions. The VREP is only played during IVR with audio trial. The visual input while wearing the HMD entirely covered the participants' immediate surroundings, as is customary with IVR. However, a mixed reality feature unique to this program permitted a real-world visual perspective of the treadmill overlayed by the IVR environment to ensure safety while walking. Ambient noise that could potentially interfere with the immersion, such as talking within the testing environment, were eliminated.



Figure 1. Equipment used during the immersive virtual reality treadmill conditions.

 © 2027 ARD Asociación Española

Participants completed each trial on a treadmill (Horizon Fitness, Cottage Grove, WI, USA) while wearing a chest-strapped heart rate monitor (Polar H9, Polar Electro Oy, Kempele, Finland). Heart rate (HR) data were collected using the associated Polar mobile app.

Experimental procedures

One study investigator assessed each participant individually. At the beginning of each session, the investigator provided standardized instructions. Participants were then instructed to familiarize themselves with the Borg Rating of Perceived Exertion (RPE) scale, which ranges from 6 to 20. Heart rate (HR) was continuously monitored throughout all sessions, and both average and peak HR were recorded for each session.

In the control condition (CON), IVR was not used, and participants walked on a treadmill while viewing only the laboratory environment. The treadmill was set to a constant speed of 3.5 mph with a 0° incline. All exercise conditions were standardized with a fixed workload within and across sessions to ensure accurate comparison between trials. In the IVR without audio (IVR-WOA) condition, participants were immersed in a virtual environment with no accompanying audio, representing a solely visual manipulation. In the IVR with audio (IVR-WA) condition, participants were immersed in the same virtual environment while listening to the VREP, resulting in both visual and auditory manipulation.

Participants were asked to report their RPE every 5 minutes during each 20-minute exercise session.

Each session lasted 20 minutes. Rest periods between sessions continued until participants' heart rate returned to within 5% of their resting HR. Trial order was randomized across participants to minimize systematic order effects. Because all three conditions were completed within the same experimental visit, formal carryover effects were not modeled. After completing the final session, participants were asked to report any symptoms of eye strain, discomfort, or nausea, and responses were recorded.

Statistical analysis

A repeated-measures design was used to evaluate differences across three conditions: CON, IVR-WOA, and IVR-WA during a standardized 20-minute treadmill walk. Repeated-measures ANOVA was performed to assess the effects of condition, time, and their interaction on RPE. Separate repeated-measures ANOVAs were conducted for heart rate variables. Where significant effects were observed, paired-samples *t* tests were used for post hoc comparisons. Pairwise comparisons were not adjusted for multiple testing and were interpreted as exploratory. Effect sizes were calculated using Cohen's d_z. Ninety-five percent confidence intervals (CIs) were computed for mean differences. Statistical significance was set at $p < .05$.

RESULTS

Eighteen participants (11 women; *M* age = 20 years, *SD* = 0.7; *M* height = 174 cm, *SD* = 9.0; *M* body mass = 69 kg, *SD* = 10.6; *M* body fat = 20%, *SD* = 6.0) completed the entire protocol. A repeated-measures analysis demonstrated a significant condition × time interaction for RPE, indicating that perceived exertion changed differently across conditions during the 20-minute treadmill walk (Table 1). Although RPE increased over time in all conditions, the IVR-WA condition produced a significantly lower RPE at 20 minutes compared with both CON ($p = .001$) and IVR-WOA ($p < .001$). Average and peak heart rate were significantly lower in both IVR conditions than in CON, with no significant differences between IVR-WOA and IVR-WA. These exploratory findings suggest that immersive VR was associated with lower cardiovascular responses, whereas the

addition of auditory input was specifically associated with lower perceived exertion during standardized treadmill walking.

Table 1. Repeated-measures ANOVA and pairwise comparisons for perceptual and cardiovascular responses during steady-state submaximal treadmill exercise.

Outcome	Overall ANOVA *F*	Overall *p*	Pairwise comparison	Mean difference	95% CI	Pairwise *p*	Cohen's d_z
RPE - 5 min	0.39	.682	None	—	—	—	—
RPE - 10 min	0.98	.386	None	—	—	—	—
RPE - 15 min	2.42	.104	None	—	—	—	—
RPE - 20 min	10.15	< .001	IVR-WA vs CON	−1.22	[−1.90, −0.55]	.001	−0.90
			IVR-WA vs IVR-WOA	−1.11	[−1.56, −0.66]	< .001	−1.23
Average HR	6.34	.005	IVR-WA vs CON	−11.89 bpm	[−18.57, −5.21]	.002	−0.88
			IVR-WOA vs CON	−9.78 bpm	[−18.29, −1.27]	.027	−0.57
Peak HR	4.94	.013	IVR-WA vs CON	−6.06 bpm	[−10.22, −1.89]	.007	−0.72
			IVR-WOA vs CON	−7.22 bpm	[−13.32, −1.12]	.023	−0.59

Note. CON = control condition; IVR-WA = immersive virtual reality with auditory stimulus; IVR-WOA = immersive virtual reality without audio; HR = heart rate; RPE = rating of perceived exertion; CI = confidence interval. Cohen's d_z represents the standardized mean difference for paired observations. Pairwise comparisons were not adjusted for multiple testing.

The strongest effects were observed for RPE at 20 minutes and average heart rate, demonstrating that immersive virtual reality with auditory input attenuated both perceived exertion and cardiovascular strain during identical steady-state exercise.

Although RPE responses at 5, 10, and 15 minutes were not statistically significant, the significant condition × time interaction demonstrated that perceptual divergence between conditions progressively increased throughout the exercise bout (Table 2).

Table 2. Repeated-measures analysis of variance for ratings of perceived exertion.

Effect	F	*p*
Condition	3.02	.062
Time	50.93	< .001
Condition × Time interaction	5.09	< .001

Note. RPE = rating of perceived exertion.

DISCUSSION

This experiment evaluated the effects of immersive virtual reality (IVR) on cardiovascular and perceived effort responses during fixed treadmill exercise across three conditions: a control without IVR or auditory stimulation (CON), IVR only (IVR-WOA), and IVR with auditory stimulation (IVR-WA).

The two outcome domains responded to different components of the manipulation. Visual immersion was sufficient to alter the cardiovascular response but did not measurably change perceived effort, whereas adding scene-matched auditory input altered perceived effort without producing further cardiovascular change. Rather than a graded response in which each additional sensory channel confers proportionate benefit, the pattern suggests that the autonomic and perceptual consequences of immersive sensory augmentation have different sensory requirements. We interpret this dissociation as the principal contribution of the study.

 © 2027 ARD Asociación Española

Perceived exertion

The perceptual finding is the more consequential of the two, both because it was the more robust and because perceived difficulty is among the barriers most often implicated in exercise discontinuation. Since treadmill speed and grade were identical across conditions, any difference in perceived exertion represents a change in the subjective cost of an otherwise unchanged exercise bout.

The reduction in RPE during the sensory-augmented exercise can also be interpreted within the psychobiological model of endurance performance (Marcora et al., 2009; Pageaux, 2014). This framework proposes that perceived effort is the primary variable that governs motor outputs. Under this model, exercise performance is determined by the relationship between perceived effort and potential motivation or the maximum tolerable perception of effort. As perceived effort approaches the maximum tolerable perceived effort, there will be an increase in afferent feedback leading to decreases in motor output and performance. Importantly, the auditory stimulus used in the present study was deliberately non-musical and contained no rhythmic beat, lyrics, or motivational content. Thus, the observed perceptual response should be distinguished from effects reported with music-based exercise interventions, in which rhythmic entrainment, arousal, motivation, and affective responses may contribute to changes in perceived exertion.

Given the central machinery that generates and evaluates perceived effort is sensitive to interoceptive and sensory signals, the cortical weight of these signals is likely reduced during IVR. Given the matched workload on the treadmill, the motor command and corollary discharge are presumably the same across conditions, but attentional manipulation could adjust the other factors that modulate perceived effort, which are the interoceptive signals.

A purely capacity-based reading of that framework does not, however, account for the full pattern. If perceived effort falls in proportion to the attentional resources an external stimulus consumes, visual immersion should have lowered perceived exertion, since it captured sufficient attention to alter the cardiovascular response. It did not. Only when congruent environmental audio accompanied the same visual environment did perceive effort change. Two non-exclusive readings are available. The first is that the visual manipulation captured less attention than a fully occluding display would have, because the mixed reality feature used here retained a real-world view of the treadmill for safety, and that the auditory layer supplied the additional capture required. The second is that the auditory layer acted less by adding competing stimulation than by completing the simulated environment: a visual scene presented in silence leaves the auditory sense to be stimulated by the real laboratory, and supplying scene-matched sound reduces that mismatch. Naef et al. (2022) describe this misalignment directly, noting that current immersive systems stimulate only a subset of the senses and that closer alignment between real and virtual input produces greater immersion. Consistent with the second reading, Jones and Wheat (2023) found that immersion in a stimulus, rather than the sense of presence it generated, predicted distraction from bodily sensations during exercise. The present design cannot distinguish these accounts, and we advance the interpretation as a proposal rather than a demonstration.

The perceptual effect was not present from the outset but emerged progressively across the bout, as indicated by the condition × time interaction. This is consistent with an attentional account in which interoceptive signal strength accumulates with exercise duration, so that a manipulation acting on the cortical weighting of those signals becomes detectable only once there is sufficient signal to attenuate. A non-exclusive alternative is that perceived exertion during the early minutes of light walking was constrained near the lower anchor of the Borg scale, limiting the range over which any between-condition difference could be expressed.

This intervention is also mechanistically distinct from the music-based auditory manipulations that dominate the exercise literature. Music reduces perceived exertion partly through attentional dissociation, but additionally through rhythmic entrainment, movement synchronisation, arousal regulation, and its affective and motivational qualities, all of which operate independently of any accompanying visual environment (Karageorghis & Priest, 2012). The playlist used here contained no tempo, beat, or motivational content, and its elements were selected for correspondence with the canyon environment rather than for musical properties. Dissociation and environmental congruence are therefore the only candidate routes it shares with music, which is what makes the absence of a perceptual effect in the visual-only condition informative.

Cardiovascular responses

The autonomic effects of manipulating attention and focus are inconsistent in the existing data. One within-subjects study had participants cycle at low (40% VO_{2max}) and moderate (60% VO_{2max}) intensities, each with and without their preferred music (Yamashita et al., 2006). Because the music and no-music conditions were matched for intensity, any perceptual difference could not be attributed to metabolic demand. Music lowered perceived exertion during low-intensity exercise but produced no corresponding autonomic change; heart rate and heart rate variability varied with exercise intensity in the absence of music but not in its presence. The authors interpreted this as a distraction effect at low intensity that did not extend to the autonomic nervous system. That dissociation, in which an auditory manipulation altered perceived effort without a detectable autonomic correlate, is the pattern the auditory layer produced here. Other data using music during light-intensity isometric exercise found small heart rate differences, with heart rate lower during music than during a simple distraction task (Moore et al., 2024). A separate study used immersive virtual reality during recumbent cycling at ventilatory threshold in overweight, inactive adults, reporting affective and prefrontal hemodynamic responses but no autonomic measures, leaving its autonomic effects unknown (Jones & Ekkekakis, 2019).

The most direct precedent for the present design comes from outside the exercise context. Naef et al. (2022) decomposed immersive VR into its sensory components, comparing combined audiovisual nature stimuli against auditory-only, visual-only, and no artificial sensory input in supine participants. Heart rate was lowest during the audiovisual and visual-only conditions, whereas the steadiest reduction in respiration rate, the lowest blood pressure, and the greatest reported reduction in awareness of the surrounding environment occurred only when both channels were delivered together. The authors attributed the heart rate pattern to the perceptual dominance of vision, which they argued is often sufficient on its own to substitute for real-world sensory input. Their auditory stimulus was constructed much as ours was, from nature sounds matched to the visual scene and delivered without spatialisation. The present cardiovascular results reproduce that pattern during exercise: visual immersion was sufficient, and scene-matched audio conferred no additional benefit.

The reduction in average heart rate during the treatments may be explained by a reduction in sympathetic activation and increase in parasympathetic activation. Since the treadmill conditions were held constant between the control and intervention conditions, metabolic demand should have been equivalent. Therefore, differences in cardiovascular responses cannot be attributed to oxygen consumption or muscular work and instead, are likely due to changes in autonomic balance, specifically decreased sympathetic drive. The cardiovascular response to sensory augmentation appeared to be largely saturated by visual immersion, with no evidence that a second sensory channel extended it.

An important distinction when interpreting this finding is differentiating between exercise-induced sympathetic activation, which supports cardiovascular delivery to working muscle through precisely intensity-matched

 © 2027 ARD Asociación Española

alterations in sympathetic and parasympathetic outflow (Fisher et al., 2015), and psychologically-driven sympathetic activation arising from anticipation (Miyamoto et al., 2022). The latter component exceeds what is metabolically required for the workload itself, reflecting psychological context rather than physiological necessity. We posit that the treatments did not reduce the metabolically-driven component of sympathetic activation, which would be physiologically unfavourable as this component supports the cardiovascular response to exercise (Fisher et al., 2015). Instead, we propose that they reduced the anticipatory and psychologically-driven component associated with monitored laboratory exercise. The fact that this displacement was apparently complete with visual immersion alone suggests the anticipatory component is reduced by attentional capture as such and does not require the more complete environmental simulation afforded by combined audiovisual input.

The proposed mechanism for this attenuation is attentional dissociation: immersive VR captures visual attentional resources and directs them toward the external virtual environment rather than the body, reducing cortical processing of the interoceptive signals that would otherwise contribute to anticipatory sympathetic activation (Craig, 2002). Attentional displacement alone does not specify the direction of the autonomic effect, since the content toward which attention is displaced also matters; the calm, non-threatening character of the environment used here is therefore likely part of the explanation rather than incidental to it.

These cardiovascular findings warrant caution. Because the pairwise comparisons were not adjusted for multiple testing, the cardiovascular findings should be interpreted cautiously, particularly those involving the visual-only condition. The perceptual finding is considerably more robust than the cardiovascular one, and we do not claim that auditory stimulation altered cardiovascular responses.

Dissociation between outcomes

The differential pattern of statistical significance across HR and RPE outcomes is consistent with shared but partially distinct central substrates for autonomic regulation and effort perception. However, the specific pathways and processes involved in each may have different sensitivities to attentional manipulation, with the autonomic component requiring less comprehensive sensory input to show measurable change than the perceptual component. Rather than treating the HR and RPE findings as independent effects, we interpret them as related manifestations of a common upstream change in central processing and attentional dissociation, expressed through pathways with different thresholds for sensory input. This interpretation is proposed rather than demonstrated and requires designs that manipulate auditory content independently of visual immersion across a wider range of outcomes.

Novelty warrants separate consideration. Both immersive conditions were equally unfamiliar relative to control and condition order was randomized, so the perceptual difference between IVR with and without audio cannot be attributed to first-exposure novelty. Novelty remains a plausible contributor to the cardiovascular differences from control, however, since both immersive conditions differed from control in familiarity as well as in sensory content, and no familiarisation session preceded data collection. Novelty-driven effects would be expected to attenuate with repeated exposure.

Translational implications

Perceived exertion is not merely a descriptive outcome but rather plays a substantial role in long-term exercise habits. Affective response during a single acute bout of exercise prospectively predicts self-reported physical activity participation at both six and twelve months in previously sedentary adults (Williams et al., 2008), and the affective experience of exercise is increasingly argued to belong alongside effectiveness and safety among the criteria governing how exercise is prescribed (Ekkekakis et al., 2011). We note explicitly

that these findings concern affective valence rather than perceived exertion, and that neither affect nor subsequent behaviour was measured here; the link between the present perceptual result and adherence is inferential.

These findings have practical implications for endurance training and people new to exercise with adherence-related difficulties. Given that most US adults do not meet aerobic activity guidelines (Piercy et al., 2018) and that roughly half of those beginning an exercise program discontinue within six months (Robison & Rogers, 1994), interventions that reduce the subjective burden of a bout without reducing its metabolic demand are of direct public health relevance. The perceptual reduction observed here is modest in isolation, but it acts on the variable that behavioural models identify as a determinant of continued participation, and the auditory layer that produced it adds negligible cost to an already-deployed visual intervention.

If immersive sensory environments reduce the psychological stress component of exercise without compromising the metabolically-driven cardiovascular response, this could translate to performance benefits under conditions where exercise is self-paced rather than externally constrained. Our study used a fixed treadmill protocol, which prevents direct measurement of performance effects, but the psychobiological framework predicts that participants exercising at self-selected intensity or in time-to-exhaustion protocols would show improved performance under sensory-augmented conditions. Lower perceived effort at any given physiological demand would allow either greater sustainable workload at equivalent perceived effort, or greater duration at equivalent workload, before reaching the motivational ceiling that triggers disengagement. This prediction is untested in the present data and is offered as a hypothesis rather than an implication. The most useful applications of this effect are likely in training contexts where reduced perceived strain is itself the goal, rather than maximal performance contexts where high effort tolerance must be developed. For recreational and beginner runners, the perceived difficulty of exercise is a primary barrier to adherence; reducing perceived effort at submaximal workloads through comprehensive sensory engagement may meaningfully improve the subjective experience of exercise and support sustained engagement.

Beyond recreational fitness, the populations for whom perceived exertion is most limiting are often those in whom exercise is most clinically indicated. Cardiac and pulmonary rehabilitation, weight management programs, and clinical populations in whom symptom perception rather than cardiorespiratory capacity constrains participation are candidate settings, as are workplace and home-based programs, given that treadmill-compatible head-mounted displays are now widely available at consumer cost. One qualification bears directly on these applications: at the light intensity used here, affective responses to exercise are pleasant for most individuals, and the affective constraint on adherence emerges principally at intensities approaching and exceeding the ventilatory threshold (Ekkekakis et al., 2011). Whether the perceptual benefit observed here persists at the intensities where it would matter most for adherence is untested. Extension to clinical populations, higher intensities, or repeated exposure is a matter for future work rather than an implication of these data.

Limitations

Several limitations apply to these findings. First, the small sample size must be acknowledged. With eighteen participants, the smallest within-subject effect that the design could reliably detect corresponds to a moderate-to-large standardized difference. Rather than claiming significance would be reached in a larger sample, we posit that the present design could not distinguish a small true effect from no effect. Pairwise comparisons were not adjusted for multiple testing and should therefore be interpreted as exploratory, particularly given the modest sample size. Although the auditory content was standardized, sound intensity was not calibrated using an objective sound-pressure measure; therefore, the absence of formal volume

 © 2027 ARD Asociación Española

standardization should be considered when interpreting and reproducing the auditory condition. Participants were recruited without prior virtual-reality experience, and a separate standardized IVR familiarization session was not conducted; consequently, novelty associated with initial IVR exposure cannot be excluded as a potential influence. Detailed headset display settings and software configuration parameters beyond the device, application, and virtual environment reported in the Methods were not prospectively recorded, which may limit exact replication of the IVR conditions. The environmental auditory stimuli were selected by the investigators for their perceived correspondence with the virtual canyon environment; however, audiovisual congruence was not formally assessed or rated by participants. Additionally, the study did not include an audio-only or incongruent-audio condition; therefore, the present design cannot determine whether the observed perceptual effect resulted specifically from audiovisual congruence or from the addition of environmental auditory stimulation more generally. To this end, the sample was young, homogeneous, and drawn from a single site. These results may not apply to older participants spanning different regions and backgrounds. Additionally, given that this was a single session intervention, these results must be interpreted as strictly acute effects.

The visual manipulation was also not fully occluding. A mixed reality feature retained a real-world visual perspective of the treadmill to ensure safety during walking, so the immersive conditions did not remove real-world visual input entirely. This raises the possibility that the visual channel captured less attention than the immersive framing implies. Furthermore, blinding is not feasible for a head-mounted display intervention and expectancy effects cannot be excluded for a self-reported outcome such as perceived exertion.

Although our findings point towards reduced sympathetic drive based on lower heart rate measures, our design did not directly measure sympathetic activation. This explanation would be strengthened by direct measures such as heart rate variability or salivary cortisol.

Additionally, while immersion is a central aspect of the IVR intervention, we did not precisely measure presence, immersion, enjoyment, or affective valence. These additional variables would provide further insight into the link between immersion and the audio condition.

The design used in this study lacked conditions that would isolate the auditory mechanism. An audio-only condition would establish whether the soundscape reduces perceived exertion in the absence of the corresponding visual environment. More directly, an incongruent audio condition, presenting non-scene-matched sound at matched loudness, would distinguish an account based on environmental congruence from one based simply on additional competing stimulation, since the two accounts make opposite predictions for such a condition. These represent valuable directions for future research.

CONCLUSION

Immersive sensory engagement during fixed treadmill exercise was associated with reductions in average heart rate, peak heart rate, and RPE, with significant differences emerging at different points across conditions. Both immersive conditions reduced average and peak heart rate relative to control, and adding an auditory stimulus produced no further cardiovascular reduction beyond visual immersion alone. Perceived effort was significantly reduced with IVR and an auditory stimulus compared to control and IVR alone. These findings suggest that an auditory stimulus may be necessary for the perceptual benefit, which visual immersion alone did not produce**,** and that the cardiovascular and perceptual consequences of immersive sensory augmentation may have different sensory requirements. Because the perceptual finding was both the larger and the more robust of the two, the practical value of adding congruent environmental audio to an

immersive exercise environment lies in the subjective experience of the bout rather than in its cardiovascular response.

AUTHOR CONTRIBUTIONS

All authors meet the criteria for authorship in accordance with established ethical guidelines. Contributions are specified according to the CRediT (Contributor Roles Taxonomy) as follows:

Conceptualisation: B. A. D. Methodology: B. A. D. Formal analysis: B. A. D., J. P., T. Y. Investigation: B. A. D. Data curation: B. A. D., J. P., T. Y., J. A. K., N. T., T. K. S. Writing – original draft: B. A. D., J. P. Writing – review & editing: B. A. D., J. P., T. Y., J. A. K., N. T., T. K. S. Supervision: B. A. D.

All authors have critically reviewed and approved the final version of the manuscript and agree to be accountable for all aspects of the work.

FUNDING

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

CONFLICT OF INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this manuscript.

ETHICS COMMITTEE APPROVAL

This study was performed in accordance with the ethical standards of the Declaration of Helsinki and was approved under a single Institutional Review Board protocol (sIRB: BRANY, NY, USA). All participants provided written informed consent.

AI USE DISCLOSURE

In accordance with current publishing ethics and transparency recommendations, artificial intelligence (AI) tools were used solely to assist with translation and language editing, with the aim of improving clarity and readability. No AI tools were used in the generation of scientific content, including the study design, data collection, analysis, interpretation of results, or the formulation of conclusions. The authors retain full responsibility for the content of the manuscript and confirm its originality, integrity, and accuracy.

ACKNOWLEDGEMENTS

We are grateful to the researchers from the UCFIT Digital Health- Exercise Physiology Research Laboratory for their dedication to the study, as well as the participants that gave their time, energy, and full effort.

REFERENCES

Barbour, B., Sefton, L., Bruce, R. M., Valmaggia, L., & Runswick, O. R. (2024). Acute psychological and physiological benefits of exercising with virtual reality. *PLOS ONE*, *19*(12), e0314331. https://doi.org/10.1371/journal.pone.0314331

 © 2027 ARD Asociación Española

Craig, A. D. (2002). How do you feel? Interoception: The sense of the physiological condition of the body. *Nature Reviews Neuroscience, 3*(8), 655–666. https://doi.org/10.1038/nrn894

Ekkekakis, P., Parfitt, G., & Petruzzello, S. J. (2011). The pleasure and displeasure people feel when they exercise at different intensities: Decennial update and progress towards a tripartite rationale for exercise intensity prescription. *Sports Medicine, 41*(8), 641–671. https://doi.org/10.2165/11590680-000000000-00000

Fisher, J. P., Young, C. N., & Fadel, P. J. (2015). Autonomic adjustments to exercise in humans. *Comprehensive Physiology, 5*(2), 475–512. https://doi.org/10.1002/cphy.c140022

Hutchinson, J. C., Karageorghis, C. I., & Jones, L. (2015). See hear: Psychological effects of music and music-video during treadmill running. *Annals of Behavioral Medicine, 49*(2), 199–211. https://doi.org/10.1007/s12160-014-9647-2

Hutchinson, J. C., & Tenenbaum, G. (2007). Attention focus during physical effort: The mediating role of task intensity. *Psychology of Sport and Exercise, 8*(2), 233–245. https://doi.org/10.1016/j.psychsport.2006.03.006

Jones, L., & Ekkekakis, P. (2019). Affect and prefrontal hemodynamics during exercise under immersive audiovisual stimulation: Improving the experience of exercise for overweight adults. *Journal of Sport and Health Science, 8*(4), 325–338. https://doi.org/10.1016/j.jshs.2019.03.003

Jones, L., & Wheat, J. (2023). Green and pleasant lands: The affective and cerebral hemodynamic effects of presence in virtual environments during exercise. *Perceptual and Motor Skills, 130*(2), 826–843. https://doi.org/10.1177/00315125221146614

Karageorghis, C. I., & Priest, D.-L. (2012). Music in the exercise domain: A review and synthesis (Part I). *International Review of Sport and Exercise Psychology, 5*(1), 44–66. https://doi.org/10.1080/1750984X.2011.631026

Marcora, S. M., Staiano, W., & Manning, V. (2009). Mental fatigue impairs physical performance in humans. *Journal of Applied Physiology, 106*(3), 857–864. https://doi.org/10.1152/japplphysiol.91324.2008

Miyamoto, T., Sotobayashi, D., Ito, G., Kawai, E., Nakahara, H., Ueda, S., Toyama, T., Saku, K., Nakanishi, Y., & Kinoshita, H. (2022). Physiological role of anticipatory cardiorespiratory responses to exercise. *Physiological Reports, 10*(5), e15210. https://doi.org/10.14814/phy2.15210

Mocco, A., Valmaggia, L., Bernardi, L., Alfieri, M., & Tarricone, I. (2024). Enhancing physical activity with immersive virtual reality: A systematic review. *Cyberpsychology, Behavior, and Social Networking, 27*(5), 303–317. https://doi.org/10.1089/cyber.2023.0394

Moore, A. R., Hutchinson, J. C., Winter, C., Dalton, P. C., Bolgla, L. A., & Paolone, V. J. (2024). Music alters heart rate and psychological responses but not muscle activation during light-intensity isometric exercise. *Sports Medicine and Health Science, 6*(4), 394–401. https://doi.org/10.1016/j.smhs.2024.01.008

Naef, A. C., Jeitziner, M.-M., Knobel, S. E. J., Exl, M. T., Müri, R. M., Jakob, S. M., Nef, T., & Gerber, S. M. (2022). Investigating the role of auditory and visual sensory inputs for inducing relaxation during virtual reality stimulation. *Scientific Reports, 12*(1), 17073. https://doi.org/10.1038/s41598-022-21575-9

Pageaux, B. (2014). The psychobiological model of endurance performance: An effort-based decision-making theory to explain self-paced endurance performance. *Sports Medicine, 44*(9), 1319–1320. https://doi.org/10.1007/s40279-014-0198-2

Piercy, K. L., Troiano, R. P., Ballard, R. M., Carlson, S. A., Fulton, J. E., Galuska, D. A., George, S. M., & Olson, R. D. (2018). The physical activity guidelines for Americans. *JAMA, 320*(19), 2020–2028. https://doi.org/10.1001/jama.2018.14854

Robison, J. I., & Rogers, M. A. (1994). Adherence to exercise programmes: Recommendations. *Sports Medicine, 17*(1), 39–52. https://doi.org/10.2165/00007256-199417010-00004

Rutkowski, S., Szary, P., Sacha, J., & Casaburi, R. (2021). Immersive virtual reality influences physiologic responses to submaximal exercise: A randomized, crossover trial. *Frontiers in Physiology, 12*, 702266. https://doi.org/10.3389/fphys.2021.702266

Williams, D. M., Dunsiger, S., Ciccolo, J. T., Lewis, B. A., Albrecht, A. E., & Marcus, B. H. (2008). Acute affective response to a moderate-intensity exercise stimulus predicts physical activity participation 6 and 12 months later. *Psychology of Sport and Exercise, 9*(3), 231–245. https://doi.org/10.1016/j.psychsport.2007.04.002

Yamamoto, T., Sahni, T. K., McCabe, C. A., Nguyen, T. L., Blatney, A. E., Lechner, R. J., Nguyen, T. H., Benna, D. M., Farrales, J. P., Mologne, M. S., Neufeld, E. V., & Dolezal, B. A. (2024). Deceptive modulation of actual and perceived effort while walking using immersive virtual reality: A teleoanticipatory approach. *Applied Sciences, 14*(14), 6072. https://doi.org/10.3390/app14146072

Yamashita, S., Iwai, K., Akimoto, T., Sugawara, J., & Kono, I. (2006). Effects of music during exercise on RPE, heart rate and the autonomic nervous system. *The Journal of Sports Medicine and Physical Fitness, 46*(3), 425–430.

This work is licensed under a Attribution-NonCommercial-ShareAlike 4.0 International (CC BY-NC-SA 4.0).

 © 2027 ARD Asociación Española